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Resilience of Transportation Systems to Disasters

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Background

- In a transportation system (a railway system, a bus system etc.), as long as there is at least one way (either direct or in direct, either one way or round trip) to get from a station A to another station B, we can assume that a thing (a piece of information, product, virus etc.) can eventually get from station A to station B. If the stations are far away from each other, it may take some time for the thing to "travel", but we can assume that it will eventually reach "destination".
- So, from this perspective, we can say that there is not a 100% "safe" station if every station is not isolated.
- However, depending on how a transportation system is constructed (location of each station relative to the entire network, number of stations in the entire network etc.), a transportation system can be quicker in spreading the thing (distributing information, virus, goods etc.) than another system.
- Keep in mind that whether this quickness is good or bad depends on our interpretations (what context do we interpret, what is the thing that "travels").

Model

- We modeled transportation systems as networks, with stations representing vertices and the routes representing the edges between stations.

Centrality measures used for quantifying resilience

- Formal definition of **betweenness centrality**: $C_B(i) = \sum_{j,k} \frac{P_{jk}(i)}{P_{jk}}$, for i, j and $k \in N$ and $i \neq j \neq k$
- Formal definition of **normalized betweenness centrality**: $C'_B(i) = \frac{C_B(i)}{\sum_j C_B(j)}$, for i and $j \in N$
- Formal definition of **closeness centrality**: $C(x) = \frac{1}{\sum_y d(y,x)}$
- Formal definition of **normalized closeness centrality**: $C(x) = \frac{N-1}{\sum_y d(y,x)}$

Results

- Figure 5 and Figure 6 show top 5 stations in the Delhi metro with highest centrality measures.
- Although not shown here, for each station in each of the four metros, we calculated its betweenness centrality (CBi), normalized betweenness centrality (CB'i), closeness centrality (CCi), and normalized closeness centrality (CC'i).
- We were able to calculate CBi with CB'i at the same time, and CCi with CC'i at the same time, because the normalized ones will not change the ranking.

Figure 5

```
In [4]: delhiBetweennessTopFive()
Delhi Metro Top 5 Stations by CBi, CB'i
-------------
             Station                CBi                  CB'i
       Kashmere Gate   8216.03333333333  0.012791721742776794
     Dilli Haat -INA  7853.383333333338  0.012227104037150247
 Mayur Vihar Phase-1  7782.933333333325  0.012117418893454137
           Hauz Khas  7679.000000000001  0.011955602816783005
         Rajiv Chowk  7372.066666666667  0.011477731606395635
```

Figure 6

```
In [6]: delhiClosenessTopFive()
Delhi Metro Top 5 Stations by CCi, CC'i
-------------
             Station                    CCi                 CC'i
         Rajiv Chowk  0.0002886836027713626  0.07505773672055427
         Mandi House  0.0002841716396703609  0.07388462631429384
 Central Secretariat  0.0002838489923360772  0.07380073800738007
     Dilli Haat -INA  0.00028336639274582036  0.07367526211391329
         Patel Chowk  0.0002813731007315701  0.07315700619020822
```

Possible interpretations

- In the context of natural disasters, a transportation system, which has a few stations with high betweenness centralities, has a relatively low resilience.
- In the context of virus spread, a transportation system, which has stations with high closeness centralities, has a relatively low resilience.

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A transportation system with a few stations of high betweenness centralities is more vulnerable to disasters.

A transportation system with stations of high closeness centralities is more vulnerable to disease spread.

Objectives

- Understand the resilience of transportation systems relative to disasters.
- Use network theory to model the transportation systems.
- Use centrality measures to mathematically quantify the resilience of transportation systems.
- Interpret the results according to the real-world scenario.

Brief Description of Our Research

- We decided to quantify the resilience of four metros in the Indian subcontinent, which are Delhi Metro (Figure 1), Mumbai Railway (Figure 2), Bangalore Metro (Figure 3), and Chennai Metro (Figure 4).
- We modeled each metro as a **network** (see *Model* section).
- We used **centrality measures** (see *Centrality measures used for quantifying resilience* section) to quantify the resilience of each metro.

Figure 1

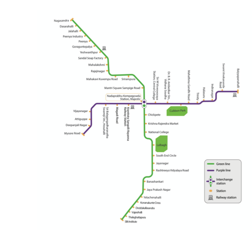

Figure 3

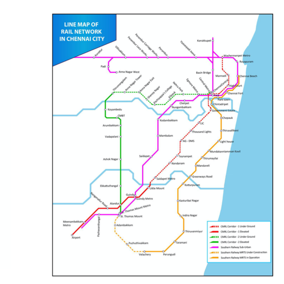

Figure 4

Figure 2

Steps

- First step: did literature review
- Second step: collected data
- Third step: encoded the maps as CSV files
- Fourth step: drew the networks. As the drawn networks are HTML files, we could not include them in this poster.
- Fifth step: wrote Python code to compute centrality measures of all stations in four metros and to display them in decreasing order.

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Future work

- All Indian metros should be modeled using networks and quantified using the above set of centrality measures. This will help create a more accurate picture of the resilience of the entire Indian metro system.
- Other factors, such as demography, should be considered in future work to calculate a more accurate resilience of any transportation system.

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